Poultry Waste Generation and Land Application in the Illinois River Watershed and Phosphorus Loads to the Illinois River Watershed Streams and Rivers and Lake Tenkiller

Expert Report of Dr. B. Engel

For
State of Oklahoma
In Case No. 05-CU-329-GKF-SAJ

State of Oklahoma v. Tyson Foods, et al.
(In the United States District Court for the Northern District of Oklahoma)

Dr. B. Engel, P.E.
Professor of Agricultural and Biological Engineering

May 22, 2008

Bernard Engel, Ph.D., P.E.

EXHIBIT
3

2. Review of Illinois River Watershed Studies - P Contribution

Numerous studies have explored P loads in the Illinois River Watershed (IRW) to the streams and rivers within the watershed and to Lake Tenkiller. ***Analysis of these reports indicates that poultry waste application to pastures within the watershed is a substantial contributor to P in the streams and rivers of the watershed and to Lake Tenkiller.***

The majority of these studies indicate that P in the streams and rivers within the IRW has increased over time. These studies consistently conclude that nonpoint sources of P are a substantial contributor to total overall P loads to the Illinois River, its tributaries, and Lake Tenkiller. When these studies identified the source of nonpoint source P, they consistently identify land application of poultry waste as the primary nonpoint source. Information is summarized from these reports in the remainder of this section.

Observed data and models indicate nonpoint source pollution is the major contributor to P loads within the streams and rivers of the IRW and to Lake Tenkiller. Poultry waste application within the IRW to pastures is identified as the major and a substantial contributor to overall P loads within IRW streams and rivers and Lake Tenkiller.

The USGS (Terry et al., 1984) conducted an extensive water quality study on the Illinois River above Lake Frances from September 1978 to September 1981. The study concluded that existing water quality in the Illinois River, and several tributaries, did not meet the Arkansas State Guideline of 100 ug/l total phosphorus (as P) in streams.

Oklahoma's 305(b) Report (Oklahoma Department of Pollution Control, 1984 as reported by Gade (1998)) included an assessment of trends for certain water quality parameters at USGS gauging stations 07195500 (Illinois River at Watts), 07196000 (Flint Creek near Kansas, OK), 07196500 (Illinois River near Tahlequah), and 07197000 (Baron Fork near Eldon, OK) for the period from 1975 to 1983 done by the Oklahoma Department of Pollution Control (ODPC). The report concluded there was an apparent increasing trend in concentrations of total phosphorus at all four stations.

Walker (1987 as reported by Gade (1998)) reviewed EPA's STORET data base and Gakstatter and Katko's data (1986 as reported by Gade (1998)) and concluded that phosphorus concentrations have increased by a factor of roughly two to three over the past decade. Walker used flow-weighted annual mean total P concentrations to develop conclusions about trends. He suggested it would be proper to compare years of comparable flow to determine if total phosphorus concentrations had indeed increased. Walker also concluded the most probable cause for accelerated eutrophication in Lake Tenkiller is increased point source nutrient loadings since nonpoint sources tend to be rich in nitrogen while point sources tend to be rich in phosphorus (Walker, 1987 as reported by Gade (1998)). Walker's interpretation is incorrect because poultry waste contains significant amounts of P that is not in proportion to plant needs. Thus, when poultry waste has been applied to meet the nitrogen needs of plants there is inevitably an excessive P application to pastures in the IRW.

Jobe et al. (1996) recommended a 30-40% reduction in nutrient input into Lake Tenkiller ("Clean-Lakes" Diagnostic and Feasibility Study on Tenkiller Lake, Oklahoma).

The authors of Illinois River Water Quality, Macroinvertebrate and Fish Community Survey explored EPA STORET data. At the Savoy station, total P load increases slightly despite high P peaks in mid 80s. They noted that peak values seem to be in response to increased runoff.

Burks and Kimball (1988 as reported by Gade (1998)) performed a study evaluating existing concentrations of nutrients transported by the Illinois River to make an assessment of the potential effects of water quality in Lake Tenkiller. They used QUAL2E (a water quality model) on the lower reaches of the Illinois River above Lake Tenkiller and the upper segment of Lake Tenkiller. They found a projected decrease in P input from Tahlequah's WWTP after construction and implementation of a P removal system would be adequate in reducing the rate of eutrophication in Lake Tenkiller. However, they concluded that other point and non-point sources within the basin would still contribute to the further deterioration of water quality in Lake Tenkiller. They recommended concerted efforts to public and private agencies to reduce P input into Lake Tenkiller to prevent further deterioration.

Harton (1989 as reported by Gade (1998)) performed a modeling study of the Illinois River in an attempt to analyze contributions of point and nonpoint source P loading on Lake Tenkiller. The Fayetteville wastewater treatment plant effluent was determined to have no observable effect on eutrophication in Lake Tenkiller. Harton concluded the substantial distance from the point of entry of the effluent into the Illinois River to Lake Tenkiller was sufficient to allow for nearly total removal by biological activity. Nonpoint Source (NPS) total P loadings from Oklahoma and Arkansas were found to be the main loading sources to the lake. Harton concluded that removal of 70-90% of the total P loading from point and nonpoint sources would be necessary to bring eutrophication under control in Lake Tenkiller.

Burks et al. (1991 as reported by Gade (1998)) evaluated factors affecting water quality in the Illinois River. In-stream total P concentration exceeded the 0.1 mg/l level recommended by the EPA (US EPA, 1986) to prevent enrichment of streams or tributaries to standing bodies of water. They suggested there was "overwhelming evidence" that P loading to the upper end of Lake Tenkiller was excessive, and predicted decreases in water quality for the lake. Total N loading also was shown to be increasing over time. They suggested strict reduction of both point and nonpoint nutrient inputs into the system, and suggested that the focus be placed on P.

The Phase I Diagnostic and Feasibility Study on Tenkiller Lake (OWRB, 1996) found that mean annual concentrations of P, N, and chlorophyll a measured throughout Lake Tenkiller were indicative of eutrophic conditions. Recommendations for control of eutrophication were focused on the reduction of P from both point and nonpoint sources.

Gade (1990 as reported by Gade (1998)) presented temporal trend tests (Kendall Tau) on flow adjusted concentrations of total P at USGS gauging stations 07195500 (Illinois River at Watts, OK), 07196000 (Flint Creek near Kansas, OK), 07196500 (Illinois River near Tahlequah, OK), and 07197000 (Baron Form Creek near Eldon, OK) all indicated highly significant upward trends for the period from 1976 to 1986.

Phillips (2007) summarizes several studies that have been conducted on the IRW and its waters, including Lake Tenkiller, that document excess P in these waters and the source of the excess P. Phillips concludes that poultry waste application to soils in the IRW has contributed to the historical water quality problems within the IRW and Lake Tenkiller.

Nelson et al. (2002) analyzed 5 years of observed P data in the Illinois River at the Arkansas Highway 59 bridge just prior to the Illinois River reaching Oklahoma. TP load at the Illinois River near the Arkansas-Oklahoma border is about 208,000 kg where 45% of the annual loading is from municipal WWTPs (Haggard et al., 2003). Up to 83% of the average annual P loading from municipal WWTPs in the Illinois River can be attributed to a single WWTP (Springdale, Arkansas – see Section 6 of this report for further discussion) (Nelson et al., 2002). However, in 2003 the WWTP loads were decreased significantly such that the total load in the IRW draining to Lake Tenkiller is approximately 90,000 lb annually (compared to 226,000 lb prior to 2003). Haggard and Soerens (2006) indicated that WWTPs in the IRW have recently adopted a 1 mg/L P standard for discharge.

Nelson et al. (2002) also performed a P mass balance for the Arkansas portion of the Illinois River Watershed. They concluded that even if point sources were eliminated, the P concentrations in the Illinois River at the sampling location on Arkansas Highway 59 would exceed the 0.037 mg P standard. Their analyses identify poultry waste spread on pastures as the primary source of the nonpoint source (NPS) P in the Illinois River at Arkansas Highway 59.

Green and Haggard (2001) examined phosphorus and nitrogen concentrations and loads at the Illinois River south of Siloam Springs, Arkansas between 1997 and 1999. They found that flow-weighted nutrient concentrations and nutrient yields at the Illinois River site were about 10 to 100 times greater than national averages for undeveloped basins. Most of the phosphorus load was contributed during surface runoff. On average, base flow contributed 15 percent of the annual total phosphorus load; surface runoff contributed 85 percent of the annual total phosphorus load. On average, 72 percent of the soluble reactive phosphorus annual load was contributed during surface runoff.

Haggard et al. (2002) examined phosphorus concentrations and loads in the State of Oklahoma's scenic rivers (The Baron Fork, Flint Creek, and the Illinois River) between 1998 and 2000. They found that approximately 39% of the 367,000 kg/yr phosphorus load to Lake Tenkiller from the Illinois River and Baron Fork was in the dissolved form, and over 94% of the phosphorus load was transported during surface runoff. Annual phosphorus loads were least in 1999 (232,000 kg/yr) but were greatest in the following year (506,000 kg/yr in 2000). Lake Francis, a small impoundment near the Arkansas-Oklahoma border, retained about 26 % of the phosphorus transported from Arkansas to Oklahoma in the Illinois River. Phosphorus yields (kg/km^2) and flow-weighted concentrations from the IRW were about 10 times greater than values reported for undeveloped basins, nationally and regionally (Haggard et al. (2002)).

Pickup et al. (2003) observed phosphorus concentration for the Illinois River Basin, in Arkansas and Oklahoma between 1997and 2001. These data were used to calculate P loads and yields. Phosphorus concentrations in the Illinois River basin generally were significantly greater in runoff-event samples than in base-flow samples. Loads appeared to generally increase with time during 1997-2001 at all stations, but this increase might be partly attributable to the beginning of runoff-event sampling in the basin in July 1999. Runoff components of the annual total phosphorus load at USGS gauges in the IRW ranged from 58.7 to 96.8% from 1997-2001. Mean flow-weighted concentrations were more than 10 times grater than the median and were consistently greater than the 75th percentile of flow-weighted phosphorus concentrations in samples collected at relatively undeveloped basins of the United States. The annual average phosphorus load entering Lake Tenkiller was about 577,000 pounds per year, and more than 86% of the load was transported to the lake by runoff which is predominately NPS P.

Tortorelli and Pickup (2006) observed phosphorus concentrations in the Illinois River Basin, Arkansas and Oklahoma between 2000-2004. They used this data to compute P loads at IRW USGS gauging stations. Annual total loads in the Illinois River from Watts to Tahlequah increased slightly for the period 2000-2002 and decreased slightly for the periods 2001-2003 and 2002-2004. Calculated mean annual runoff loads ranged from 68-96% of the calculated mean annual total phosphorus loads from 2000-2004. Calculated mean seasonal base-flow loads were generally greatest in spring (March through May) and were least in fall (September through November). Calculated mean seasonal runoff loads generally were greatest in summer (June through August) for the period 2000-2002 but were greatest in winter (December through February) for the period 2001-2003, and greatest in spring for the period 2002-2004. The calculated mean annual phosphorus load entering Lake Tenkiller ranged from about 391,000 pounds per year to 712,000 pounds per year, and from about 83 to 90 percent of the load was transported to the lake by runoff which is predominately NPS P.

The mean load of total P was calculated to be 1180 lbs/day at the upper end of Tenkiller (Harton, 1989 as reported in Burks) of which an estimated 221 lbs/day were point sources with the remainder from nonpoint sources (73%). Nonpoint source P was estimated at 415 lbs from Arkansas and 189 lbs from Oklahoma.

Vieux and Moreda (2003) used observed P concentration data and flow data for the IRW to create a relationship between stream/river flow and P concentrations. Figures 2.1 and 2.2 show P concentrations at Watts and Tahlequah that they plotted. These P concentrations were consistently above the 50 ug/l level that has commonly been recommended as a water quality threshold. They found the majority of P loading in the IRW occurred during direct runoff events and found high concentrations of P at high flow rates and low P concentrations for low flow rates. Vieux and Moreda (2003) also noted that the P generated by the poultry industry in the IRW is equivalent to a human population of 8 million people (2000 population of the IRW is slightly more than 280,000 people). They further indicated that poultry manure is stored and then applied to pastureland. They conclude that, with the large number of poultry in the IRW, the potential for contamination by poultry manure is high. They indicate that most of the P reaching Lake Tenkiller is from NPS sources.

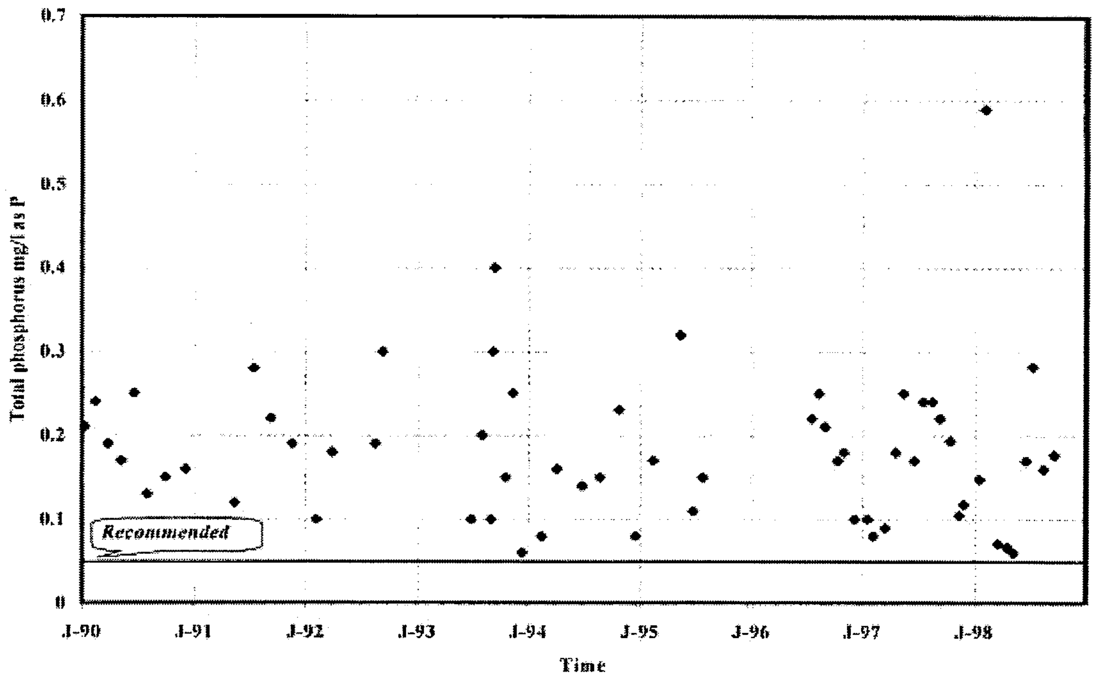

Figure 2.1. Vieux and Moreda (2002) plot of observed P at Watts Station for 1990-1998

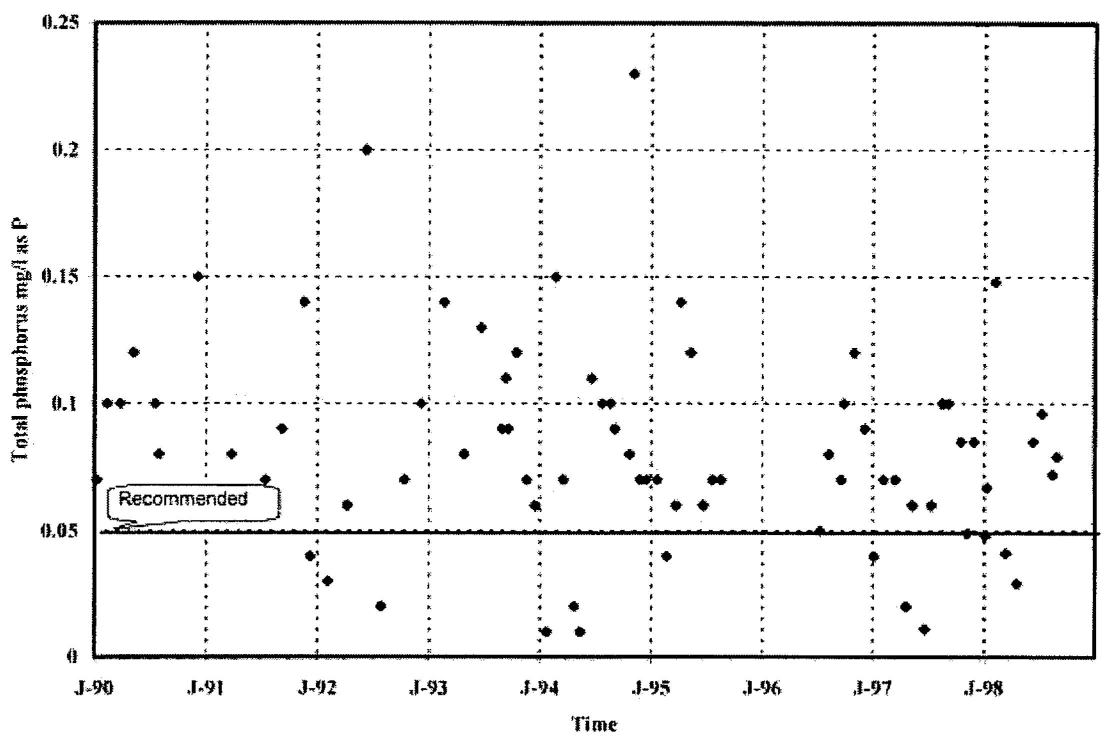

Figure 2.2. Vieux and Moreda (2002) plot of observed P at Tahlequah Station for 1990-1998

Walker (1987) used monitoring data from subwatersheds in the IRW not influenced by Waste Water Treatment Plants (WWTP) and found the average P concentration in runoff due to NPS from Arkansas was .150 mg/l and from Oklahoma was .100 mg/l.

Gade (1998) found statistically significant increasing P concentration at 07194800 (Illinois River near Savoy, AR) and 07197000 (Baron Fork Creek near Eldon, OK) for 1980-1993. Highly significant increasing total P load trends (1980-1993) were found at 07194800, 07196500 (Illinois River near Tahlequah, OK), 07196000 (Flint Creek near Kansas, OK) and 07197000.

Gade (1998) estimated P loads to Lake Tenkiller using a model of the IRW. Gade (1998) indicated that in1985 NRCS data identified 1,246 sites that had poultry houses for a total of 2,692 houses in the IRW. Gade (1998) used poultry house data to estimate P production in poultry waste, pasture applied P and pasture area by Illinois River Basin subwatershed in his modeling. The land application of P was based on house location, soil test phosphorus (STP), and distances from the houses. STP levels were highest near poultry houses. A distance from poultry houses was identified that resulted in the best fit with observed STP levels (1500-2500m). This indicates the majority of poultry waste is land applied within 2500m of poultry houses.

Gade (1998) estimated mean annual adjusted loads entering Lake Tenkiller at Horseshoe Bend are 228,000 kg P/yr. He estimated that 83.5% of P is nonpoint source pollution (190,000 kg/yr). Gade estimated that at Horseshoe Bend, the mean annual concentration of total P was 0.23 mg/l with 0.15 mg/l from nonpoint sources, 0.02 mg/l from background sources and 0.06 mg/l from point sources.

Storm et al. (1996) used SIMPLE (Spatially Integrated Model for Phosphorus Loading and Erosion) in the Illinois River basin. They used 1985 NRCS poultry house survey to calculate poultry waste P but noted there was significant expansion of the poultry industry in the Oklahoma portion of the watershed from 1985 through 1992. For the model run that considered continuous loading of P from poultry over 25 years, the average increase in P load is 324 percent. P loading was calculated at 2.30 kg/ha per year from pastures after P was applied for 25 years. Storm et al. (1996) noted that long-term reductions in P loading can only be accomplished by exporting animal manure from the watershed. They indicated that to prevent excessive buildup of soil P, litter should be diverted to fields deficient in P, and those fields with excessive soil P levels should discontinue use of poultry litter and receive nitrogen from commercial fertilizers.

Storm et al. (1996) indicated that pasture areas account for 95 percent of total nonpoint source P loading to the basin with most of this coming from pastures receiving poultry waste. They estimated that 76 percent of total P load in the IRW comes from 6 subwatersheds: Flint, Benton, Osage, Clear and Fork; although these watersheds represent 56 percent of the basin area. They indicated that overall 66 percent of P was from nonpoint source pollution (Note significant P reductions in point sources began in 2003 so this proportion would be expected to be much higher now).

Storm et al. (2006) used the SWAT in the IRW and calculated 330,000 kg/yr of total phosphorus (88,000 kg/yr was in soluble mineral forms) reached Lake Tenkiller between 1997 and 2001. They indicated point sources of P to be 35% of this total and application of litter being responsible for 15% of total phosphorus load. However, they note "This does not include the effect of increased soil phosphorus from years of poultry litter application, which increased total phosphorus load. Therefore, if litter application was suddenly eliminated, the phosphorus load would be reduced by approximately 15%. Total phosphorus load due only to elevated soil phosphorous from the application of litter was not estimated." They note that 50% of total P loads were from other NPS sources, but they did not determine the portion of this attributable to poultry.

A draft TMDL analysis was performed on the IRW and Lake Tenkiller. In reviewing the sources of nutrients, a 1989 Soil Conservation Service (USDA-SCS, 1989) inventory was reviewed that estimated more than 93,400,000 chickens and other poultry are produced in the basin each year, producing 366,000,000 kilograms of manure. Gade (1998) indicates the poultry litter cleaned from poultry houses is spread over open pastures and barren fields. The report concludes that eutrophication in Lake Tenkiller is most sensitive to changes in P loading. A 25 percent reduction in P loading was required for lake water quality to satisfy the target criteria. Point sources were estimated to contribute 23% of P to Lake Tenkiller while urban and cropland contribute 5.6% of P, and pasture (with litter) contributes 56% of P.

Smith et al. (1997) analyzed HUCs (watersheds) to identify the contributors of nutrients to streams and rivers. For the Illinois River Watershed, they found that livestock contributed 93.01 kg P per square km per year (out of a total of 118.29 kg P per square km per year), while point sources contributed 5.33 kg P per square km per year and fertilizer contributed 8.52 kg P per square km per year. The Smith et al. (1997) analysis indicates livestock are responsible for 78.63% of P in the Illinois River while point sources represent 4.5% and fertilizer represents 7.21%.

Smith and Alexander (2000) mapped P contributions from livestock as shown in the figure below (Figure 2.3). The Illinois River Watershed was identified as having between 50 and 83% of P loads in runoff attributable to livestock (more than 78% based on Smith et al. (1997)). They found that compared to national data, the Illinois River P contributions from livestock are among the highest in the nation.

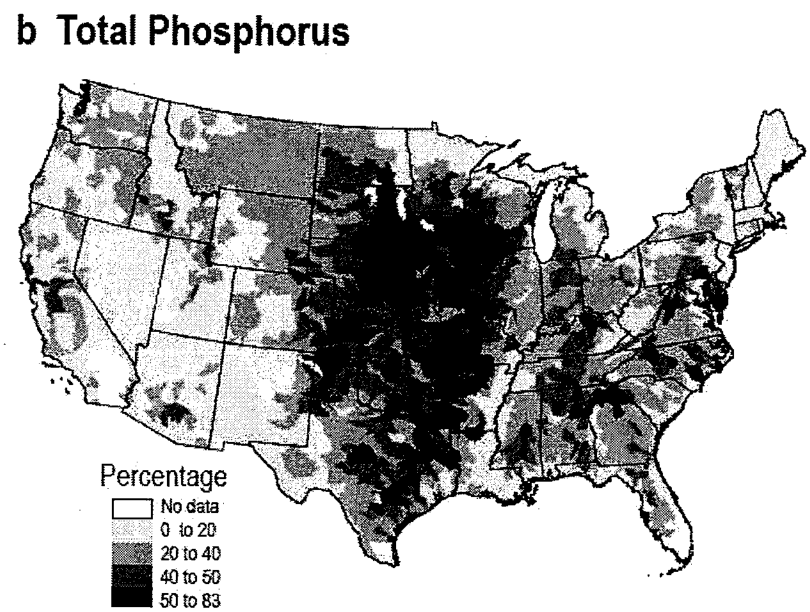

Figure 2.3. Contributions of animal agriculture to nutrient export from hydrologic units (watersheds) (from Smith and Alexander (2000))

Appendix A summarizes additional journal papers that complement the reports and literature reviewed in this section. These materials further support the analysis conducted throughout this report.

Appendix A

Overview of Related Literature

McDowell, R.W., Sharpley, A.N., Beegle, D.B., Weld, J.L. (2001). "Comparing phosphorus management strategies at a watershed scale." *Journal of Soil and Water Conservation*, 56(4), 306-315.

Starting with the premise that "The ultimate goal of P management is to balance P inputs to farm with outputs in primary production such that no excess P is applied and soil P concentrations are kept at an optimum level for agronomic performance and minimal environmental impact," this article examined three management scenarios of the USDA-EPA *Unified National Strategy for Animal Feeding Operations* to reduce phosphorus from a watershed (p. 306). Using a "site assessment phosphorus index" they found that none of the watershed was at high risk of phosphorus loss and that those areas with medium were near the stream channel. Of the three strategies, the authors endorse the phosphorus index strategy because it can take into account landscape variables that affect phosphorus loss and can "focus on defining, targeting and remediating fields that combine high soil P concentrations with areas of high erosion and overland flow potential," (p. 313). Essentially, this paper endorses the P index management strategy because it can discriminate areas that have the greatest risk of P loss from those that have lower risks of P loss and can, therefore, treat them differently.

Schärer, M., Stamm, C., Vollmer, T., Frossard, E., Oberson, A., Flühler, H., Sinaj, S. (2007). "Reducing phosphorus losses from over-fertilized grassland soils proves difficult in the short term." *Soil Use and Management*, 23(1), 154-164.

This article examines three management options for reducing P runoff from grassland soils. They found that, although omitting the application of P fertilizer would reduce soil P in the long term, more drastic measures were needed to achieve P loss reductions in the short term. They found that establishing a new P equilibrium in the soil takes years and cannot be accelerated, so it is especially important to stop further build-up of P as soon as possible. So, the article essentially says that short-term treatments are inadequate to solve the problem, so stopping further P from being applied is extremely important and is probably the only way to solve the problem.

Hansen, N.C., Daniel, T.C., Sharpley, A.N., Lemunyon, J.L. (2002). "The fate and transport of phosphorus in agricultural systems." *Journal of Soil and Water Conservation*, 57(6), 408-417.

This article investigates the importance of each transport pathway (runoff, soil interflow, deep leaching) as affected by soil type and management. The paper notes that it can take "many years to reduce P concentration in soils with a high STP concentration" (415). The ultimate conclusion that they reach for reducing P losses is site risk assessment; identifying sites with a high potential of P movement to surface water and then implementing management practices to reduce P losses from those sites.

Edwards, D.R., Daniel, T.C., Scott, H.D., Moore Jr., P.A, Murdoch, J.F., Vendrell, P.F. (1997). "Effect of BMP implementation on storm flow quality of two northwestern Arkansas streams." *American Society of Agricultural Engineers*, 40(5), 1311-1319.

This article examined whether a program of Best Management Practice (BMP) is effective at reducing storm stream flow concentrations and mass transport of nutrients. They found that significant decreases (from 23 to 75% per year) in both concentrations and mass transport of nutrients occurred concurrently with BMP implementation.

Kleinman, P.J.A., Sharpley, A.N. (2003). "Effect of broadcast manure on runoff phosphorus concentrations over successive rainfall events." *Journal of Environmental Quality*, 32(1), 1072-1081.

This article evaluates the effects of manure application rate and type on runoff P concentrations. They found that the application rate of manure was related to runoff P due to increased concentrations of dissolved reactive phosphorus in runoff. That is, as the application rate increased, so did the contribution to DRP in runoff TP. Additionally, poultry and swine manure treatments tended to have higher DRP concentrations than runoff from dairy manure treatment. Repeated rainfall diminished the differences in runoff DRP and differential erosion of broadcast manure caused significant differences in runoff TP concentrations between soils. Essentially, increasing rates of manure application were associated with a higher proportion of runoff TP as DRP, which indicates that soluble P losses from manure become increasingly important at higher rates of application.

McDowell, R.W., Sharpley, A.N. (2001). "Approximating phosphorus release from soils to surface runoff and subsurface drainage." *Journal of Environmental Quality*, 30(1), 508-520.

This article investigates the P release from the surface in relation to the concentration of P in surface runoff and subsurface damage. They found a change point above which P increased at a greater rate per unit increase in STP than if below the change point. They note that the change point in STP may be used in support of agricultural and environmental P management.

Sharpley, A.N., McDowell, R.W., Kleinman, P.J.A. (2001). "Phosphorus loss from land to water: integrating agricultural and environmental management." *Plant and Soil*, 237, 287-307.

This article argues that the overall goal of efforts to reduce P loss to water should involve balancing P inputs and outputs at farm and watershed levels by optimizing animal feed rations and land application of P as mineral fertilizer and manure. They found that the loss of P originates primarily from small areas within watersheds during a few storms. These areas are those with high soil P, or P application in mineral fertilizer or manure.

DeLaune, P.B., Moore Jr., P.A., Carman, D.K., Sharpley, A.N., Haggard, B.E., Daniel, T.C. (2004). "Evaluation of the phosphorus source component in the phosphorus index for pastures." *Journal of Environmental Quality*, 33(1), 2192-2200.

This article evaluates the P index for pastures by applying poultry litter to test plots and by evaluating watersheds that had been fertilized with poultry litter for over ten years. The small plots indicated that soil test P, by itself, was a poor predictor of P concentrations in runoff water and that the relationship between P in runoff and the amount of soluble P applied was highly significant. The pastures with natural rainfall and annual poultry litter application indicated that the P index for pastures predicted P loss accurately without calibration. "These data indicate that the P index for pastures can accurately assess the risk of P loss from fields receiving poultry litter applications in Arkansas and provide a more realistic risk assessment than threshold soil test P levels."

Wang, X., Harmel, R.D., Williams, J.R., Harman, W.L. (2006). "Evaluation of EPIC for assessing crop yield, runoff, sediment and nutrient losses from watersheds with poultry litter fertilization." *American Society of Agricultural and Biological Engineers*, 49(1), 47-59.

This article is an evaluation of the Environmental Policy Integrated Climate (EPIC) model version 3060 and looked at runoff of several watersheds when poultry litter was added. The model accurately predicted surface P runoff on an annual, monthly, and daily basis for al watersheds. So, they conclude that EPIC is able to successfully replicate the environmental impact of poultry litter application on runoff, water quality, and crop yields.

DeLaune, P.B., Moore Jr., P.A., Carman, D.K., Sharpley, A.N., Haggard, B.E., Daniel, T.C. (2004). "Development of a phosphorus index for pastures fertilized with poultry liter – factors affecting phosphorus runoff." *Journal of Environmental Quality*, 33(1), 2183-2191.

This article evaluates the effects of multiple variables on P concentrations in runoff water and tries to construct P source component of a P index for pastures that incorporates these effects. Their goal is to see if recent studies that show that other factors are more indicative of P concentrations in runoff from areas where manure is being applied than an upper limit on soil test phosphorus. They found that, without manure, soil test P was directly related to soluble P concentrations in runoff water. After the poultry litter was applied, soil test P had little effect on P runoff. In other words, "once manure was applied, SRP concentrations in runoff were not correlated to Mehlich-III P, but were highly correlated to the SRP concentrations in the applied manure (2189)." So, P runoff increased with increasing soluble P concentration in the manure. They also found that runoff P varied based on the type of manure applied, with alum-treated litter having the lowest P runoff, and commercial P fertilizer and HAP or phytase litter having the highest P runoff.

Mancl, K.M., Slates, J.D. (2003). "Farmer Estimates of Manure Application Rates." Symposium, Ninth International Animal, Agricultural and Food Processing Wastes Proceedings, 200-203.

This article looks at the ability of livestock producers and growers to make visual estimates of manure application rates. Of the 101 participants, 13% estimated at or near the actual application rate, 22% estimated high application rates, while 65% underestimated the manure application rate (with 50% estimating less than one-half the actual application rate). Relying on visual estimates without training, 50% would have applied twice the desired application rate. Thus, they conclude that the tendency to underestimate manure application and therefore over-apply manure reinforces the need to calibrate spreading equipment as a part of a manure management plan.

Gitau, M.W., Chaubey, I., Nelson, M.A., Pennington, J.H. (2007). "Analyses of BMP and land use change effects in a Northwest Arkansas agricultural watershed." ASABE Paper N. 072244. St. Joseph, Mich.: ASABE.

This article seeks to quantify the effects of implementation, timing, and spatial distribution of the Best Management Practices (BMPs) on sediment and nutrient loss reduction and watershed ecological integrity. From an analysis of historical land use and BMP implementation, they found a 9% increase in urban areas and an 11% decrease in pastured areas between 1992 and 2004. During this time about 10% of the watershed was in transitional land use, and BMP implementation increased from less than 1% to 34% of the watershed area. Also during this time, sediment loss declined by 22%, total phosphorus losses declined by 11%, and total nitrogen losses increased by 11%.

Kleinman, P.J.A., Sharpley, A.N. (2003). "Effect of broadcast manure on runoff phosphorus concentrations over successive rainfall events." *Journal of Environmental Quality*, 32, 1072-1081.

This article evaluates the effects of manure application rate and type on runoff P concentrations from acidic agricultural soils over successive runoff events. The runoff boxes were broadcast with three types of manure and simulated rainfall was applied. They found that application rate of manure was related to runoff P, due to increased concentrations of dissolved reactive phosphorus in runoff; as application rate increased, so did the concentration of DRP in the runoff total phosphorus. Swine and poultry manure showed higher DRP concentrations in runoff than dairy manure.

White, M.J., Storm D.E., Stoodley, S., Smolen, M.D. (2003). "Modeling the Lake Eucha basin with SWAT in 2000." ASAE November Conference, 536-542.

The SWAT model predicted that the application of poultry litter elevated soil test phosphorus in the basin and is responsible for 49% of the current annual phosphorus load to the lakes.

Sen, S., Srivastava, P., Yoo, K., Dane, J.H., Shaw, J.N., Kang, M.S. (2007). "Runoff generation mechanism in the Appalachian plateau region of Alabama – a field investigation." ASABE Paper No. 072090. St. Joseph, Mich.: ASABE.

This article attempts to delineate spatial and temporal distribution of hydrologically active areas (HAAs) and identify surface runoff generation mechanism using distribution sensors. This research is a response to the failure of Alabama's P-index to account for differences in P loss, from poultry litter, across specific fields within a single watershed. They found that the surface runoff generation mechanism is mostly infiltration excess (rather than saturation excess) and that certain hydrologic characteristics seem to play a dominant role in surface runoff generation in this specific region of Alabama. Additionally, they further conclude that the ability to predict the spatial and temporal distribution of HAAs can be predicted by a few variables, would lead to significantly better management of P from land-applied poultry litter.

Gitau, M.W., Gburek, W.J., Jarrett, A.R. (2005). "A tool for estimating best management practice effectiveness for phosphorus pollution control." *Journal of Soil and Water Conservation*, 60(1), 1-10.

As a response to P runoff from farms that had reached the New York City water supply, this study establishes a means of estimating BMP effectiveness, based on data available in the literature, and develops a tool that allows users to obtain BMP effectiveness estimates for their respective site soil and slope conditions.

Secchi, S., Gassman, P.W., Jha, M., Kurkalova, L., et al. (2007). "The cost of cleaner water: Assessing agricultural pollution reduction at the watershed scale." *Journal of Soil and Water Conservation*, 62(1), 10-21.

This study, performed for the Iowa Department of Natural Resources, outlines a methodology to simultaneously assess economic costs and water quality benefits associated with the hypothetical placement of a broad set of conservation practices. Annual costs range from $300 to $597 million and predicted sediment decreases from 6-65%, total P from 28-59%, and nitrate from 6-20%.

Buczko, U., Kuchenbuch R.O. (2007). "Phosphorus indices as risk-assessment tools in the U.S.A. and Europe – a review." *Journal of Plant Nutrition and Soil Science*, 170, 445-460.

This article reviews the factors of P loss which are taken into account in P indices and different modifications of P indices according to their components and structural approach. Essentially, this article looks at the different P indexes that exist and divides them into three groups: (1) additive approach, (2) multiplicative approach, and (3) multiplicative-aditive approach.

Pote, D.H., Daniel, T.C., Nicholas, D.J., Moore Jr., P.A., Miller, D.M., Edwards, D.R. (1999). "Seasonal and soil-drying effects on runoff phosphorus relationships to soil phosphorus." *Soil Science Society of America Journal*, 63, 1006-1012.

This article investigates the possibility that the correlation between increased concentrations of dissolved reactive P (DRP) in runoff from grassland and increased soil test P (STP) levels are affected by seasonal changes in field conditions and the practice of air-drying soil samples prior to analysis. They found that all correlations of STP to runoff DRP were significant, regardless of seasonal changes or STP method. Additionally, they found that DRP concentration in August runoff was almost double that of May runoff. So, seasonal changes can make a difference.

Tesfaye, D., Storm, D.E., Payton, M.E., Smolen, M.D., Basta, N.T., Zhang, H., Cabrere, M.L. (2004). "Spatial and temporal scaling effects on hydrology and phosphorus loss in runoff from pastures." ASAE Paper No. 042271.

This article attempts to investigate: the interaction of explanatory variables and their effects on response variables, the spatial and temporal scaling effects on hydrology, and DRP and TP losses in runoff from pastures. They found that DRP loss from pastures was significantly influenced by poultry liter, rainfall duration, pasture height, plot size, rainfall intensity, and runoff duration.

Erb, K.A. (2002). "Phosphorus loading per acre vs. cow populations in a dairy watershed in Northeast Wisconsin." ASAE Publication No. 2010P0102.

This article conducted a study to determine per-hectare rate of nitrogen, phosphorus, and potassium loading on farms in the Lower Fox River Basin over two years. The mass balance showed an average of 98 kg/ha nitrogen accumulation, 17kg/ha phosphorus accumulation, and 90 kg/ha potassium accumulation on dairy farms. Cash grain accumulation rates were 10, 3, and 26 kg/ha, respectively. Most of the dairy farms had already implemented nitrogen based nutrient management plans. "The study indicates that phosphorus accumulations could be reduced by more that 90% by implementing a number of additional management practices, including switching to lower phosphorus protein supplements, growing rather than purchasing protein sources, reducing the amount of phosphorus in the dairy ration, and reallocating manure across the farm to fields with the greatest phosphorus need."

Soupier, M.L., Mostaghimi, S., Yagow, E.R. (2006). "Nutrient transport from livestock manure applied to pastureland using phosphorus-based management strategies." *Journal of Environmental Quality*, 35, 1269-1278.

Recognizing that land applications of manure from confined animal systems and direct deposit by grazing animals are both major sources of nutrients in streams, this paper attempts to determine the effects of P-based manure applications on total suspended solids and nutrient losses from dairy manures and poultry litter surface applied to pasturelands and to compare the nutrient losses transported to the edge of the field during overland flow events. The study found that the nutrients are most transportable from cowpies, so a buffer zone between pastureland and streams or other appropriate management practices are necessary to reduce nutrient losses to waterbodies.

Haggard, B.E., Storm, D.E., Stanley, E.H. (2001). "Effect of a point source input on stream nutrient retention." Journal of the American Water Resources Association, 37(5), 1291-1299.

This article examined the effect of a point sources input on water chemistry and nutrient retention in an Arkansas creek. They found that, although no single factor is responsible for nutrient retention, discharge and the level of nutrient enrichment explained a substantial amount of the observed variance in the SRP.

Srinivasan, M.S., Gerard-Marchant, P., Veith, T.L., Gburek, W.J., Steenhuis, T.S. (2005). "Watershed scale modeling of critical source areas of runoff generation and phosphorus transport." Journal of the American Water Resources Association, 361-375.

This article evaluated Soil Moisture Distribution and Routing (SDMR) and SWAT by applying them to a watershed in Pennsylvania in order to identify runoff generation areas. Neither simulation matched the observed data over all seasons, but SWAT is better able to predict time series stream flow. However, neither model allows runoff routing across the watershed.

Kornecki, T.S., Sabbagh, G.J., Storm, D.E. (1999). "Evaluation of runoff, erosion, and phosphorus modeling system – SIMPLE." Journal of the American Water Resources Association, 35(4), 807-820.

This article evaluates the performance of Spatially Integrated Models for Phosphorus Loading and Erosion (SIMPLE) in predicting runoff volume, sediment loss, and phosphorus loading from two watersheds. SIMPLE tended to underestimate runoff volumes during the dormant period and the comparison between observed and predicted dissolved phosphorus showed better correlation than for observed and predicted total phosphorus loading.

Sharpley, A., Kleinman, P., Weld, J. (2004). "Assessment of best management practices to minimize the runoff of manure-borne phosphorus in the United States." *New Zealand Journal of Agricultural Research*, 47, 461-477.

This article demonstrates that the P Index can provide flexible and reliable manure management and provide farmers with options to minimize the risk of P loss.

Kronvang, B., Vagstad, N., Behrendt, H., Bogerstrand, J., Larsen. S.E. (2007). "Phosphorus losses at the catchment scale within Europe: an overview." *Soil Use and Management*, 23(10, 104-116.

This article examines the importance of phosphorus losses from agricultural land by analyzing data and two different models for the Nordic-Baltic region of Europe.

Sharpley, A.N., Weld, J.L., Beegle, D.B., Kleinman, P.J.A., Gburek, W.J., Moore Jr., P.A., Mullins, G. (2003). "Development of phosphorus indices for nutrient management planning strategies in the United States." *Journal of Soil and Water Conservation*, 58(3), 137-152.

This article charts the development of the indexing approach, which ranks site vulnerability to P loss by accounting for source and transport factors and outlines modifications made among States to the P index that reflect local conditions and policy. The conclude that using three management scenarios (changing the time of applied manure, riparian buffer establishment, and reduced feed P ration) that overall P index ratings can be decreased, giving farmers more options for manure management than by simply reducing application rates.

Kleinman, P.J.A., Needelman, B.A., Sharpley, A.N., McDowell, R.W. (2003). "Using soil phosphorus profile data to assess phosphorus leaching potential in manured soils." *Soil Science Society of America Journal*, 67(1), 215-224.

This article investigates whether detailed description and interpretation of soil P profile data provide adequate insight into P leaching potential. They ultimately conclude that soil P profile data appear to provide only limited insight into P leaching potential.

Gaudreau, J.E., Vietor, D.M., White, R.H., Provin, T.L., Munster, C.L. (2002). "Response of turf and quality of water runoff to manure and fertilizer." *Journal of Environmental Quality*, 31, 1316-1322.

This article evaluates responses of bermudagrass turf and volumes and P and N concentrations of surface runoff after fertilizer or composted manure applications. They found that runoff volumes were similar between manure and fertilizer sources of P and that dissolved P concentration in runoff during a rain even was five times greater for fertilizer than for manure P.

Kleinman, P.J.A., Sharpley, A.N., Moyer, B.G., Elwinger, G.F. (2002). "Effect of mineral and manure phosphorus sources on runoff phosphorus." *Journal of Environmental Quality*, 31, 2026-2033.

This article attempts to quantify the effects of alternative P sources, application methods, and initial soil P concentrations on runoff P losses from three acidic soils. They found that runoff DRP concentrations were highly correlated with water-soluble P concentration of surface-applied manure. Additionally, practices that increase P sorption at the soil surface may reduce P loss in surface runoff, even after surface application has occurred.

Daniel, T.C., Sharpley, A.N., Lemunyon, J.L. (1998). "Agricultural phosphorus and eutrophication: a symposium overview." *Journal of Environmental Quality*, 27, 251-257.

This article provides an overview of the issues discussed at a symposium titled "Agricultural Phosphorus and Eutrophication." "Generally, the loss of agricultural P in runoff is not of economic importance to a farmer. However, it can lead to significant off-site economic impacts, in some cases occurring many miles from the P source. By the time these impacts are manifest, remedial strategies are often difficult and expensive to implement: they cross political and regional boundaries…"

Edwards, D.R., Daniel, T.C. (1994). "Quality of runoff from Fescue grass plots treated with poultry litter and inorganic fertilizer." Journal of Environmental Quality, 23, 579-584.

This article assessed the impacts of fertilizer treatment and simulated rainfalls on quality of runoff from fescue grass. After the first rainfall event, the total P runoff was highest from plots that received inorganic fertilizer, while the highest concentrations of chemical oxygen demand and total suspended solids occurred in runoff from plots treated with poultry litter. The runoff from the second and third rainfall events were not significantly different than the control. So, the first rainfall event is significantly worse than subsequent rainfall events.

Pote, D.H., Daniel, T.C., Sharpley, A.N., Moore Jr., P.A., Edwards, D.R., Nichols, D.J. (1996). "Relating extractable soil phosphorus to phosphorus losses in runoff." Soil Science Society of America Journal, 60, 855-859.

This paper tested the hypothesis that soil test P correlates to dissolved reactive P and bioavailable P in runoff varies, depending on the extraction method. They found that there is a linear relationship between STP levels and DRP concentration in runoff from the soil surface.

Sauer, T.J., Daniel, T.C., Moore Jr., P.A., Coffey, K.P., Nichols, D.J., West, C.P. (1999). "Poultry litter and grazing animal waste effects on runoff water quality." *Journal of Environmental Quality*, 28, 860-865.

This study compares the effects of grazing animal depositions vs. poultry litter application on nutrient runoff. Plots receiving poultry litter had significantly greater losses of most nutrient parameters for both rainfall simulations. They ultimately concluded that "a severe rainfall event shortly after poultry litter application produces significantly greater nutrient losses as compared to similar application of grazing animal depositions at the rates used in the experiment.

Edwards, D.R., Daniel, T.C. (1992). "Environmental impacts of on-farm poultry waste disposal – a review." *Biosource Technology*, 41, 9-33.

This paper reviews information regarding the disposal of on-farm poultry wastes and the effects of poultry waste disposal on environmental quality.

Edwards, D.R., Daniel, T.C., Scott, H.D., Murdoch, J.F., Habiger, M.J., Burks, H.M. (1996) "Stream quality impacts of best management practices in a Northwestern Arkansas basin." Water Resources Bulletin, 32(3), 499-509.

This article attempts to asses the water quality effectiveness of best management practices implemented in the Lincoln Lake basin in Northwest Arkansas. Total P was highest for sub-basins with the highest proportion of pasture land use. The declines in analysis parameter concentrations are attributed to the implementation of BMPs in the basin.

Pote, D.H., Daniel, T.C., Nichols, D.J., Sharpley, A.N., Moore Jr. P.A., Miller, D.M., Edwards, D.R. (1999). "Relationship between phosphorus levels in three ultisols and phosphorus concentrations in runoff." *Journal of Environmental Quality*, 28, 170-175.

This study attempts to identify the most consistent STP method for predicting runoff DRP levels, and determine effects of site hydrology on correlations between runoff DRP concentrations. They found that all correlations of STP to runoff DRP were significant, which suggests the importance of site hydrology in determining P loss in runoff and may provide a means of developing a single relationship for a range of soil series.

Nelson, M.A., Cash, W.L., Steele, K.F. (2000). "Determination of nutrient loads in Upper Moores Creek." Arkansas Soil & Water Conservation Commission.

This is a report of a monitoring project of the Lincoln Lake Basin in order to demonstrate the effectiveness of the implemented BMPs in reducing nutrient transport from the pastures in the intensively managed areas.

Chapman, S.L., Moore, B.J., Barton, L. "Water quality and poultry production in three hydrologic units in Arkansas." University of Arkansas Cooperative Extension Service.

This is a report on three USDA hydrologic projects in Arkansas. They found that, although only about 30% of the soils need phosphorus fertilization for crop production, however producers continue to apply poultry litter to the land.

Sauer, T.J., Daniel, T.C., Moore Jr., P.A., Coffey, K.P., Nichols, D.J., West, C.P. (1999). "Poultry litter and grazing animal waste effects on runoff water quality." *Journal of Environmental Quality*, 28(3), 860-865.

This study compares nutrient runoff as affected by grazing animal depositions vs. poultry litter application. They found that plots receiving poultry litter had significantly greater losses of most nutrient parameters. "A severe rainfall event shortly after poultry litter application produces significantly greater nutrient losses as compared to similar application of grazing animal depositions."

Moog, D.B., Whiting, P.J. (2002). "Climatic and agricultural factors in nutrient exports from two watersheds in Ohio." *Journal of Environmental Quality*, 31, 72-83.

This article uses a statistical analysis to identify climatic, hydrologic, and agricultural variables that best explain variations in nitrate, phosphorus, and total suspended solids between 1976 and 1995 in two watersheds that feed Lake Erie. Nitrate, total suspended solids, and total phosphorus tended to decrease when previous months were wet, except in the summer, and to decrease when snow cover was extensive. Soluble reactive phosphorus loads were negatively correlated to conservation tillage and reserves, and positively correlated to fertilizer and manure sources.

Lehmann, J., Lan, Z., Hyland, C., Sato, S., Solomon, D., Ketterings, Q.M. (2005). "Long-term dynamics of phosphorus forms and retention in manure-amended soils." Environmental Science and Technology, 39, 6672-6680.

This study investigates the relationship between organic and inorganic P in soil pools and equilibrium leachate along a chronosequence of poultry and dairy manure additions in New York. They found that long-term manuring resulted in the low retention of additional P in the soil.

Sauer, T.J., Daniel, T.C., Nichols, D.J., West, C.P., Moore Jr., P.A., Wheeler, G.L. (2000). "Runoff water quality from poultry litter-treated pasture and forest sites." *Journal of Environmental Quality*, 29, 515-521.

This study attempts to measure the effect of site characteristics and poultry litter application on runoff and nutrient transport from grazed pasture and forest sites at different landscape positions. They found that poultry litter-treated plots had consistently higher concentrations of all water quality parameters tested compared to untreated plots. Additionally, concentration of DRP in runoff from untreated plots was linearly correlated with three soil P tests and soil P on litter-treated plots had little effect on runoff DRP. Finally, the results indicate that variation in runoff has a significant effect on nutrient transport from grazed pastures receiving poultry litter.

Maguire, R.O., Hesterberg, D., Gernat, A., Anderson, K., Wineland, M., Grimes, J. (2006). "Liming poultry manures to decrease soluble phosphorus and suppress the bacteria population." *Journal of Environmental Quality*, 35, 849-857.

This study evaluated the ability of CaO and CA2 for killing manure bacterial populations and stabilizing P in poultry wastes and to investigate the influence on soils following amendment with treated wastes. They found that the liming process, when used successfully, reduced plate counts and concerns about P losses in runoff following land application.

Sharpley, A., Foy, B., Withers, P. (2000). "Practical and innovative measures for the control of agricultural phosphorus losses to water: an overview." *Journal of Environmental Quality*, 29(1), 1-9.

This paper provides an overview of P management strategies to maintain agricultural production and protect water quality that were discussed at a conference. They concluded that there are many ways to control agricultural P transfer from soil to water including: optimizing fertilizer P use-efficiency, refining animal feed rations, using feed additives to increase P absorption by the animal, moving manure from surplus to deficit areas, and targeting conservation practices.

Nolen, S.L., Carroll, J.H., Combs, D.L., Staves, J.C. (1989). "Limnology of Tenkiller Ferry Lake, Oklahoma, 1985-1986." Proceedings of the Oklahoma Academy of Science, 69, 45-55.

This study is a response to deteriorating water quality in various watersheds, specifically the Illinois River Basin. The purpose of this study was to collect sufficient baseline water quality data to define current limnological conditions at Tenkiller Lake and to provide a basis for future water quality protection and monitoring.

Vadas, P.A., Krogstad, T., Sharpley, A.N. (2006). "Modeling phosphorus labile and nonlabile soil pools: updating the EPIC model." *Soil Science Society of America Journal*, 70, 736-743.

This study attempts to determine if replacing EPIC's constant sorption and desorption rate factor with more dynamic rate factors can more accurately predict changes in soil labile P on addition to and depletion of P from soils. They recommend improvements to EPIC's sorption and desorption rate factors by making them dynamic.

Vadas, P.A., Haggard, B.E., Gburek, W.J. (2005). "Predicting dissolved phosphorus in runoff from manured field plots." *Journal of Environmental Quality*, 34, 1347-1353.

This article tests a previously proposed model to predict manure P in runoff. It finds that, using independent field-plot data, original under predictions of manure runoff P can be improved by calculating P distribution fractions from measured runoff to rain ratios or adjusting runoff to rain ratios based on their degree of error.

Vadas, P.A., Harmel, R.D., Kleinman, P.J.A. (2007). "Transformations of soil and manure phosphorus after surface application of manure to field plots." Nutrition Cycle Agroecosystems, 77, 83-99.

This study monitors the manure and soil P over 14 to 17 months in field experiments in Texas and Pennsylvania following dairy and poultry manure surface application. They found that manure mass consistently decreased while manure total P was essentially constant through time. They ultimately concluded that management practices for water quality protection must consider the potential for manure P transformations to contribute dissolved P to runoff long after manure is applied.

Haggard, B.E., Soerens, T.S. (2006). "Sediment phosphorus release at a small impoundment on the Illinois River, Arkansas, and Oklahoma, USA." *Ecological Engineering*, 28, 280-287.

The purpose of this study is to evaluate P release from sediments accumulated at a small impoundment where the Illinois River flows from Arkansas into Oklahoma. They find that it is possible that the impound increases dissolved P concentrations in the Illinois River.

White, M.J., Storm, D.E., Zhang, H., Smolen, M.D. "PPM Plus: a tool to aid in nutrient management plan development." Oklahoma Cooperative Extension Service.

This article provides a general overview of PPM Plus and its applications for nutrient management planners and farm managers to evaluate the effect of BMPs before implementation.

Mcdowell, R., Sharply, A., Brookes, P., Poulton, P. (2001). "Relationship between soil test phosphorus and phosphorus release to solution." *Soil Science*, 166(2), 137-149.

This article examines the existence and behavior of a change point in soil P release. The change point is the point above which $CaCl_2$-P increases much more rapidly per unit increase in STP (soil test P) than if it is below that point. The change point varies greatly between soils and in relation to management. The change point can be predicted to within 40% after relatively few samples (as few as 8), and the 40% level is acceptable because most change points are more than 40% of the optimum STP required for plant growth. Essentially, putting phosphorus onto the ground in levels that far exceed the amount desired for plant growth, causes P levels to increase much more rapidly than it does at lower levels.

Vadas, P.A., Kleinman, P.J.A., Sharpley, A.N., Turner, B.L. (2005). "Relating soil phosphorus to dissolved phosphorus in runoff: a single extraction coefficient for water quality modeling." *Journal of Environmental Quality*, 34(1), 572-580.

This article investigates the extradition coefficients of water-extractable soil P and soil P sorption saturation. They found that the relationship between soil P sorption saturation and runoff FRP was the same for all 10 soils investigated, and exhibited a split-line relationship where runoff FRP rapidly increased at P sorption saturation values greater than 12.5%. They concluded that a test for soil P saturation may provide the most universal prediction of dissolved P in runoff, but only for non-calcareous soils. So, essentially, they found that a single value for an extradition coefficient relating to soil P can be used across a wide range of soil, hydrology, or management scenarios. Thus, this article can be used to counter the argument that a specific location is unique and that traditional modeling practices, therefore, do not apply to it.

Vadas, P.A., Gburek, W.J., Sharpley, A.N., Kleinman, P.J.A., Moore Jr., P.A., Cabrera, M.L., Harmel, R.D. (2007). "A model for phosphorus transformation and runoff loss for surface-applied maures." *Journal of Environmental Quality*, 36(1), 324-332.

This article develops a model to assess P release and transport from surface manures. It looked at data from Texas, Pennsylvania, Georgia, and Arkansas and found that 80% of the P remains in the top 2 cm, while 20% leaches deeper. The model can differentiate the effects of the sources of P in the soil, machine-applied manure, and manure applied from grazing animals. This model can help target alternative management practices that will be most effective in mitigating P loss. There is also some discussion in this article about the application of poultry manure in Arkansas.

Vadas, P.A., Kleinman, P.J.A., Sharpley, A.N. (2004). "A simple method to predict dissolved phosphorus in runoff from surface-applied manures." *Journal of Environmental Quality*, 33(1), 749-756.

This article details a simple approach to predict dissolved P release from manures based on observed trends in laboratory extraction of P in dairy, poultry, and swine manures with water over different water to manure ratios. The method was able to predict dissolved inorganic P concentrations in runoff from surface-applied manures, which indicates its potential to improve water quality models.

Sharpley, A.N., Kleinman, P.J.A., McDowell, Gitau, M., Bryant, R.B. (2002). "Modeling phosphorus transport in agricultural watersheds: processes and possibilities." *Journal of Soil and Water Conservation*, 57(6), 425-439.

This article looks at the challenges of modeling P transport and provides a conceptual framework from which process-based P transport models might be evaluated. They found that, although extraction coefficients relating soil and flow P are variable, they can be represented as a function of land cover or erosion. The article emphasizes improving current models to accurately predict P transport.

Chaubey, I., Sahoo, D., Haggard, B.E., Matlock, M.D., Costello, T.A. (2007). "Nutrient retention, nutrient limitation, and sediment-nutrient interactions in a pasture-dominated stream." *American Society of Agricultural and Biological Engineers*, 50(1), 35-44.

This article examines the effects of nutrients in a watershed in Arkansas. They found that light, not nutrients, limited algal growth. They concluded that "even nutrient-rich streams may continue to assimilate, to some extent, increased loads of P, altering the timing and magnitude of downstream transport of P.